(1)

QUARTERLY R&D STATUS REPORT - March, 1989

Reporting Period 1, 2 & 3

ARPA Order Number:	6419
Program Code Number:	8E20
Contractor:	Cornell University
Contract Number:	N0014-88-K-0591
Contract Amount:	$2,931,739
Effective Date of Contract:	July 1, 1988
Expiration Date of Contract:	June 30, 1991

Using Computer Design and Simulation to Improve Manufacturing Productivity

Principal Investigator:	John E. Hopcroft
Telephone Number:	607-255-7316
Electronic Mail Address:	hopcroft at gvax.cs.cornell.edu

Description of Progress

This paper is our first submitted R&D Status Report. Although our contract has an official starting date of July 1, 1988, we did not actually receive funds until October. At that time we began an intensive period of recruitment. Having hurdled the initial start-up period, we are now pursuing in-depth research in several major areas, as is evidenced by the following descriptions and the attached list of publications.

1. Improving the Simulation Simulation

1.1 Contact and Collision Models

Perhaps the most important development in the last six months has been the system's ability to produce elaborate models of contact and collision. When objects come into contact with each other, the simulator automatically and incrementally modifies their internal descriptions. For instance, if two objects remain in contact after an impact, the kinematic relationship between them changes. The system detects this situation and makes changes to the set of constraint equations that, along with the object motion equations, describe the behavior of the objects.

1.2 Gripping and Manipulation

The contact and collision models described above are essential to our research on gripping and manipulation of physical objects by electronic prototypes. We are studying temporary constraints between bodies in such motions as rolling or sliding an object on a flat surface, and are incorporating these motions into a model for soft-finger contact.

1.3 Solving Ordinary Differential Equations

Our goal is to design a set of tools to simplify the development of programs that numerically solve systems of ordinary differential equations (ODE). The development of an environment that allows one to describe an ODE solver using rich semantic units is underway. With this new environment, the user can solve a particular system of equations by providing the environment with a system of equations and specifying the characteristics of the desired ODE solver. The system will then assemble code schemas from libraries according to specification, combine them, optimize them, and finally produce a Fortran/C/Assembly language program that solves the particular system of differential equation. This system will be free to modify the equation using techniques from symbolic mathematics to improve stability or identify singularities, and is expected to produce code that has been optimized for a particular parallel structure.

1.4 Redesign

Using the knowledge gained from the Newton simulator, we are now redesigning a system that will be usable by a broader population. Our redesign will include:

a well-developed user-interface to eliminate the necessity of sophisticated programming skills,

advanced geometric, kinematic, and dynamic analysis modules (our current system handles dynamics fairly well, geometric issues less well, and doesn't address kinematic issues at all), a more developed control module that enables users to experiment with gripping and walking algorithms, and

better basic data structure manipulation facilities, such as a reliable equation representation, and tools for simplifying, differentiating, and evaluating data.

2. Anthropoid Walking

Essential to our research effort is the ability to validate our theories on a simulation system. To accomplish this, we hired an mechanical engineer who is interested in studying human-like walking, and who is implementing his work on the Newton simulator. These studies have many applications, including the design of walking machines that are capable of rough terrain mobility (such as stairs), computer animation, and simulation of humans for biomechanics and ergonomic design. We are interested in exploring alternative methods for achieving anthropoid walking, developing and analyzing algorithms, and implementing our methods on real machines.

In the past six months, we have developed a simplified, six-jointed model of a human torso and legs, and have implemented a hierarchical control system for controlling the walking. This system is comprised of three layers: the lowest level consists of simple PD controllers for the joints, the second level controls coordinated activities such as lifting the right leg, and the highest level consists of abstract states corresponding to regions of the state-space of the human (e.g. "stepping forward with the right leg"). In the highest level, each state is associated with a set of actions to perform. Transitions between states occur in response to sensed data. Using this method, we have able to make the model take several steps. Although we have not achieved stable walking yet, our implementations on the Newton simulator indicate that our walking looks natural, that our model is capable of some interesting behaviors, such as recovering from taking a step that is too large. We will continue to develop adaptive algorithms and to design better control methods.

3. Parallel, Distributed Control of Complex Systems

As a result of using the simulator to study walking, we have identified a key area of control. We are employing this knowledge to design a control program for systems with many degrees of freedom. Our program will handle problems that have not been traditionally addressed, such as: weak or partial specification of the goals; the ability to deal with redundancy and exploit it for robustness; division of the control task into independent, concurrent modules that can be individually developed, debugged and executed in parallel; and the ability to deal with multiple sources of sensor data in a uniform fashion.

4. Solid Modeler Robustness

One of our major breakthroughs has been in the area of solid modeler robustness. We have been able to demonstrate that all conversions of numeric data to logical data for the problem of intersecting convex polyhedra can be made logically independent, and with this knowledge have constructed an intersection algorithm for polyhedral objects that is several orders of magnitude more robust than existing codes.

We are now actively designing a robust system which can intersect a quadric solid with a plane or quadric surface. Our approach has been to emphasize consistent reasoning rather than employing highly accurate numerical analysis. A general design phase has been completed by building on aspects of the approach used in our earlier successful polyhedral system, and on refinements of the Levin method for quadric surface intersections. At this time, most of the higher-level code is in place. Future plans include completion of lower level routines, and vigorous testing of the algorithm.

5. Finite Element Method

In order to carry out simulations involving stress or elasticity of elements, we must have the ability to automatically generate finite element meshes. Therefore, we are investigating guaranteed-quality triangulations for the finite element method. This method divides a specific region into many smaller, simply-shaped regions. Although a number of algorithms have been developed to automate this process, most of them do not guarantee the quality of the resulting elements. We have developed a technique for dividing planar regions into guaranteed quality elements which are all close to equilateral triangles, and will attempt to extend this technique to the triangulation of curved surfaces and to problems in three dimensions.

6. Swept Volumes

We are exploring the problem of swept volumes, i.e. the volume swept by a polyhedral object as it moves. Applications for these studies include: the ability to predict interference between a moving robot and its environment, and the verification of machinning paths for numerical control (NC) machines. Our goal is to achieve a representation of the boundary of the swept volume, so that queries about intersections with other bodies, or graphical displays of the volume from different view-angles, can be answered relatively quickly.

Currently, we are investigating the planar case, where a combination of an analytical approach and a discrete approximation of the path yield a fast technique for computing the boundary of the swept volume. Implementations of our technique appear quite good.

Change in Key Personnel

We modified our original recruiting strategies by electing to to hire upper-level researchers during the initial stages of our grant. As the science base begins to grow, we plan to add experienced programmers to our staff for implementation purposes. Since October 1988, we have hired five research associates, two post doctoral associates, and two visiting scientists. We are also supporting two new graduate students.

Fiscal Status

Amount currently provided on contract:	$1,129,000
Expenditures and commitments to date:	$500,000
Funds required to complete work:	No additional funds - FY 89

R&D Quarterly Status Report
March, 1989

List of Papers

1. Algorithmic Control of Walking, IEEE International Conference on Robotics and Automation, 1989. J. Cremer & J. Stewart.
2. The Architecture of Newton, a General-Purpose Dynamics Simulator, IEEE International Conference on Robotics and Automation, 1989. J. Cremer & J. Stewart.
3. Generic Singularities of Robot Manipulators, IEEE International Conference on Robotics and Automation, 1989. D. Pai (with M. Leu).
4. Beyond Keyframing: An Algorithmic Approach to Control, submitted to *IEEE Computer Graphics and Applications*, J. Cremer & J. Stewart.

List of Technical Reports

1. Generic Singularities of Robot Manipulators, Tech Report #88-943, November 1988. D. Pai & M.C. Leu.
2. Interpolating Polynomials from Their Values, Tech Report #89-963, January 1989. R. Zippel.
3. Placing the Largest Similar Copy of a Convex Polygon Among Polygonal Obstacles, Tech Report #89-964, January 1989. L.P. Chew & K. Kedem.
4. An Explicit Separation of Relativised Random Polynomial Time and Relativised Deterministic Polynomial Time, Tech Report #89-965, February 1989. R. Zippel.
5. An Improved Algorithm for Labeling Connected Components in a Binary Image, Tech Report #89-981, March 1989. Xue Dong Yang.